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Using Paleoclimates to Predict Future Climate: How Far Can Analogy Go?

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An Editorial Essay

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Using the past as a guide for the future is such a familiar procedure that many non-specialists assume it is the basis for forecasts of substantial human-produced global warming in the next century. When I introduce my line of work to acquaintances outside the climate modeling cognoscenti—even to other scientists—they invariably think that the computer models I use extrapolate future climate directly from observational data. I then explain that the tools of choice, coupled ocean-atmosphere general circulation models, perform a three-dimensional simulation of Earth's climate from first-principles laws of physics, with little more input than solar luminosity and the chemical composition of the atmosphere. Of course modelers do compare their simulations of the present-day climate to observations collected over the past few decades. Predictions of future climate, however, include global warming during the next hundred years that would raise Earth's average surface temperature to a value not experienced in the last hundred thousand or perhaps even the last several million years. To directly base such predictions on observations, we must turn to geologic data that only indirectly indicates past climatic conditions.

GCMs with appropriate boundary conditions for the distant past have simulated ancient climates with occasional success (e.g., COHMAP, 1988), providing what my LLNL colleague W. Lawrence Gates calls "a vague sense of comfort" in their ability to forecast the future. Beyond such exercises few in the West have been willing to go. The paper by M. V. Shabalova and G. P. Können appearing in this issue of *Climatic Change* reminds us that Russian climatologists have long pursued a more ambitious agenda. Led by M I. Budyko, the Russians have compiled paleodata from past eras as an express guide to the regional patterns of climatic change expected in the next century. Shabalova and Können extend and clarify the work of the Budyko school. Using reconstructions by Irina I. Borzenkova of the last Ice Age and three past warm periods, they make the bold claim that all four of these eras show regional temperature changes from the present that scale linearly with a single parameter, the mean Northern Hemisphere temperature change. In other words we need only predict the average hemispheric warming in the next century to know, through the "paleoanalog method," what the regional distribution of temperature change will be.

Shabalova and Können add one important caveat: that the hemispherically averaged temperature "determines uniquely the large scale structure of an *equilibrium* climate [emphasis added]." Thus the paleoanalog method predicts not the actual, time-evolving climate of the Twenty-First Century but rather the idealized statistical equilibrium state if greenhouse gases remained fixed at some elevated level. It would take the deep oceans and continental ice sheets thousands of years to equilibrate with an atmosphere several degrees warmer than present. Thomas J. Crowley (1990) argues that the difference between ideal equilibrium and actual time-evolving climates is so great that "there may be no warm period that is a satisfactory past analog for future climate." My own opinion is less decided. For years, in response to limited computer time, climate modelers performed mainly equilibrium-ocean simulations of global warming. The main report of the Intergovernmental Panel on Climatic Change (Houghton et al., 1990), the standard reference on future climate prediction, refers only to such equilibrium calculations. If they are good enough for model-based predictions, are they not good enough for paleodata-based predictions?

A potentially more damaging criticism of the paleoanalog approach involves the data itself. Many share the feelings expressed by one American climatologist discussing a manuscript similar to Shabalova and Können's: "I get depressed and uncomfortable when I read such papers. I get depressed because of the steady stream of papers using the Russian paleodata—data that in the eyes of many Westerners has not been sufficiently validated in terms of chronology, transfer function technique, etc. Most people have never even seen them listed anywhere. I get uncomfortable because I'm sounding like a snobbish Westerner who is looking down his nose at data produced elsewhere." Shabalova and Können address this concern by providing an extensive bibliography of the Russian paleoreconstructions. Separately, an English translation of Borzenkova's thesis *Climate Change in the Cenozoic* will soon appear under auspices of the U.S.-Russian Agreement on Cooperation in the Field of Environmental Protection, part of a larger effort to merge U.S. and Russian data sets. This work will go far toward resolving the data quality issue.

My own reservations with Shabalova and Können's conclusions have more to do with how they interpret their data. Comparing the regional variations forecast by the paleoanalog method with the differences in forecasts using different past eras, they find a signal to noise ratio somewhat greater than one and proclaim, “This verifies the paleoanalog hypothesis at the regional level.” Without a statistical significance test that conclusion is, in my view, unproved, as is the claim that “the geographical distributions of the winter temperature anomalies over land in the paleodata is similar to those [anomalies] in the 1980-1990 period [compared with earlier decades].” Further reservations about the paleoanalog hypothesis arise when one thinks about methodological errors in translating geologic data into temperatures, in addition to the natural noise Shabalova and Können consider. Khesgi and Lapenis (1995) find that these additional errors are significant. However, readers of the technical literature will now be able to draw their own conclusions.

One implication of the data seems firm. As shown in Shabalova and Können’s Figure 1, the zonally averaged temperature changes (differences from the present day) for all four past eras, normalized by the globally averaged temperature change, fall nearly on a single curve as a function of latitude. This so-called universal curve has temperature changes near the Equator only a fraction of those at higher latitudes. The lack of significant tropical temperature changes for numerous past climates is supported by geologic observations independent of the Russian compilations (CLIMAP, 1976; Barron and Washington, 1982; Zachos et al., 1994). The data imply that past warm eras were warmer mainly where they are cold today, near the poles and in the interiors of continents in winter. On the other hand GCM simulations of past climates typically produce more uniform changes in which tropical sea surface temperatures rise and fall with the global mean. They generally produce too much tropical Ice Age cooling (Manabe and Broccoli, 1985) and fail to simulate “equable” temperature distributions for past warm eras (Barron et al., 1993; Sloan et al., 1994).

What are we to make of this model-data discrepancy? The optimistic view of GCMs is that they are correctly predicting global mean temperature changes such as the average warming to be expected from the anthropogenic greenhouse effect. Martin I. Hoffert and I have shown that the global mean climatic sensitivity implied by a direct interpretation of the paleodata lies within the range predicted by GCMs (Hoffert and Covey, 1992). Even in this view it is disconcerting that at the next level of detail, the equator-to-pole distribution of temperature changes, the models largely fail to agree with paleodata. A more pessimistic view from longtime model critic Richard S. Lindzen (1994) is that the equator-to-pole distribution is “more fundamental” than the global mean. Lindzen points out that changes in equator-pole temperature contrast through geologic time were likely accompanied by significant changes in oceanic and atmospheric heat transport. Thus the tropics in more “equable” eras were at about the same temperatures as they are now despite exporting more heat to higher latitudes than presently. Lindzen infers a strong negative feedback that GCMs miss (probably, he thinks, because of errors in the way they transport water to high altitudes). This negative feedback in the tropics combines with relatively positive feedbacks at higher latitudes to form a nonlinear climate system in which nontrivial global mean temperature changes arise from simply moving heat from one location to another.

For example, Lindzen and Pan (1994) propose that Ice Age climate changes were generated by variations in equator-to-pole heat transport associated with the Milankovitch cycles of insolation. They show that their mechanism can explain the 100,000-year glacial cycle that dominates the past million years. In their concluding words they fling the gauntlet before the conventional wisdom of globally averaged climatic change:

> Thus, simple, commonly used notions of climate sensitivity as employed in Houghton et al. (1990) are not relevant. Indeed, the present mechanism can readily produce major changes in climate (including, as a by product, changes in the globally averaged temperature) in systems which are profoundly insensitive to a doubling of CO_2. To assume (as was done by Hoffert and Covey 1992, for example) that major climate changes necessarily require high sensitivity to such changes in gross averaged forcing is clearly inappropriate.

It will not surprise readers that Hoffert and I disagree with this claim. Although Lindzen and Pan's theory may be a reasonable explanation of the *frequency* of glacial-interglacial transitions, it makes no quantitative predictions of their *amplitude.* Thus the statement quoted above is more a hypothesis than a conclusion. Hoffert and I find it difficult to believe that Lindzen's negative water vapor feedback can be reconciled with satellite data (Rind et al., 1991) and at the same time lead to global mean changes of several degrees, as are observed in Ice Age cycles. To resolve this issue we must progress from qualitative arguments to quantitative calculations of the sort initiated by Kirk-Davidoff and Lindzen (1993).

In short the disagreement between GCMs and paleodata should be cause for concern among those of us who subscribe to the conventional wisdom. At the very least it implies that model predictions of regional climatic changes are questionable. It is worth repeating the truism that the geologic record gives us the only "observations" of global change with magnitude comparable to that forecast for the next century by conventional-wisdom models. A more thorough and quantitative comparison of model results and the geologic data seems in order. I agree wholeheartedly with Lindzen (1994) that "our increasing knowledge of the Earth's past climate provides a valuable test-bed for our quantitative understanding of climate. Such understanding is not limited to the output of large-scale simulations."

In the traditional disciplinary environment of universities, the Geology Department infers past climates from the rock record while the Meteorology Department predicts future climates with computer models. Bringing together these two activities is necessary if we are to fully confront theory with observation (Crowley and North, 1991). Shabalova and Können's publication and related work by the Budyko school substantially advances this goal.

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References

Barron, E. J., and Washington, W. M.: 1982, Cretaceous climate: A comparison of atmospheric simulations with the geologic record, *Palaeogeog., Palaeoclim.,, Palaeoecol.* **40**, 103-133.

Barron, E. J., Fawcett, P. J., Pollard, D., and Thompson, S. L.: 1993, Model simulations of Cretaceous climates: The role of geography and carbon dioxide, *Phil. Trans. Roy. Soc. Lond. B*, **341**, 307-316.

CLIMAP Project members: 1976, The surface of the ice-age earth, *Science* **191**, 1131-1137.

COHMAP Project Members: 1988, Climatic changes of the last 18,000 years: Observations and model simulations, *Science* **241**, 1043-1052.

Crowley, T.: 1990, Are there any satisfactory geologic analogs for future greenhouse warming?, *J. Climate* **3**, 1282-1292.

Crowley, T., and North: 1991, *Paleoclimatology*, Oxford University Press, New York, 339 pp.

Hoffert, M. I., and Covey, C.: 1992, Deriving global climate sensitivity from palaeoclimate reconstructions,*Nature* **360**, 573-576.

Houghton, J. T., Jenkins, G. J., and Ephraums, J. J. (eds.): 1990, *Climate Change: The IPCC Scientific Assessment*, Cambridge University Press, Cambridge.

Kirk-Davidoff, D. B., and Lindzen, R. S.: 1993, Paper presented at the American Geophysical Union annual Fall Meeting, San Francisco, CA.

Khesgi, H., and Lapenis, A.: 1995, Estimating the accuracy of Russian paleodata, *Paleoceanography*, submitted.

Lindzen, R. S.: 1994, Climate dynamics and global change, *Ann. Rev. Fluid Mech.* **26**, 353-378.

Lindzen, R. S., and Pan, W.: 1994, A note on orbital control of equator-pole heat fluxes, *Climate Dynamics* **10**, 49-57.

Manabe, S. and Broccoli, A. J.: 1985, A comparison of climate model sensitivity with data from the Last Glacial Maximum, *J. Atmos. Sci.* **23**, 2643-2651.

Rind, D., Chiou, E. W., Chu, W., Larsen, J., Oltmans, S., Lerner, J., McCormick, M. P., and McMaster, L.: 1991, Positive water vapor feedback in climate models confirmed by satellite data, *Nature* **349**, 500-503.

Sloan, L. Cirbus, Walker, J. C. G., and Moore, T. C., Jr.: 1994: The role of oceanic heat transport in early Eocene climate, *Paleoceanogr.*, in press.

Zachos, J. C., Stott, L. D., and Lohmann, K. C.: 1994, Evolution of early Cenozoic marine temperatures, *Paleoceanog*. **9**, 353 - 387.

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